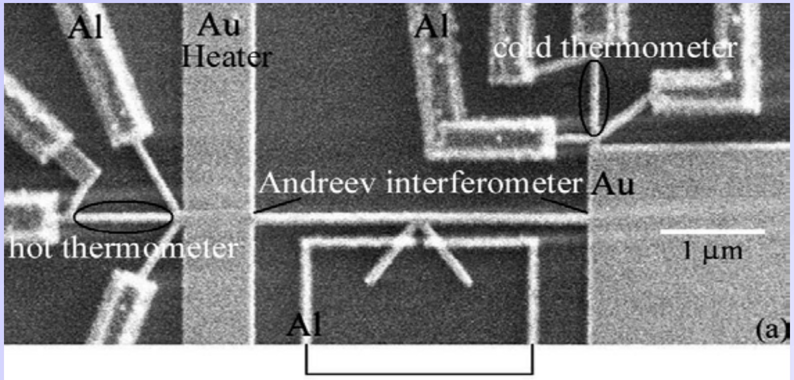
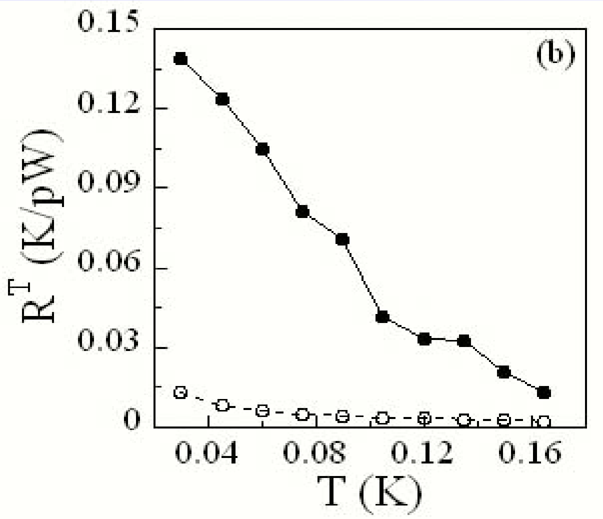
Thermal Conductance of Normal-metal/Superconductor Devices

Venkat Chandrasekhar, Northwestern University, DMR-0201530



(a) Scanning electron microscope (SEM) image of a device sitting on a 50-nm-thick Si_3N_4 membrane.



(b) Measured thermal resistance (solid dots) and the value estimated from WF law (open dots).

As the packing density of modern electronics increases, it is essential to know the mechanics of thermal transport on the micron and nanometer scale. For macroscopic canonical metals, the thermal resistance can be calculated from the Wiedemann-Franz (WF) law, knowing the electrical resistance and the temperature of the sample. In this project, we have investigated thermal transport in mesoscopic devices both experimentally and theoretically. Many of the techniques used in our research are highly relevant to nanotechnology. We have developed ultra-sensitive thermometers, which can be used to measure the local electron temperature within a 100 nm scale. We have also been able to fabricate mesoscopic devices, which are thermal isolated from the environment. For a normal metal in proximity with a superconductor, we have found that the thermal resistance is much higher than that predicted by the WF law, due to penetration of superconductivity into the normal metal. These techniques can be potentially used to study the thermal transport properties of other novel material devices.

As the size scales of electronic devices decrease, one of the critical factors limiting the speed of these devices is the ability to dissipate the heat that is generated by the currents in the circuits. Even in inexpensive desktop computers, for example, the CPUs have elaborate cooling mechanisms incorporating water circulation systems and cooling fans to conduct away the heat generated by processor. The primary cooling pathways for the heat generated in the processor are the metallic electrical leads that connect the transistors and other components on the chip. Since the widths of these interconnects in now approaching the scale of a few tens of nanometers, it is crucial to understand the effect that this small size has on the way these metallic interconnects conduct heat. Our research is focused on studying the influence of small size on the thermal conduction of small metallic and superconducting wires, and investigating the novel quantum effects that can be seen in these devices. The experimental techniques that we are developing in the process will also be applicable to investigating a host of novel nanometer scale materials and devices.

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Education:
Two graduate students, Zhigang Jiang and Paul Cadden-Zimansky, are currently working on this project. Zhigang Jiang will be completing his PhD in March 2005, and has accepted a post-doc position with Professors Horst Stormer and Dan Tsui. Paul Cadden-Zimansky is currently learning about dilution refrigerators from Zhigang, and will take over the project on related experiments later in the year. The PI has also been working with Professor Gabe Spalding and his undergraduate students at Illinois Wesleyan to set up a scanning electron microscope for use as an electron-beam writer using the lithography program developed by the PI.

Outreach:
In the summer of 2004, we hosted a high school teacher, Nathan Unterman, of Glen Brook High School, as part of the REST program. The PI also gave an introductory tutorial on Mesoscopic and Nanometer Scale at the second American Society of Mechanical Engineers NanoBootCamp, held in Evanston, in June 2004.